Grain Size and Flux Pinning in Ternary APC Nb_3Sn Wires

J. Rochester, X. Xu, X. Peng, M. Tomsic, and M. D. Sumption

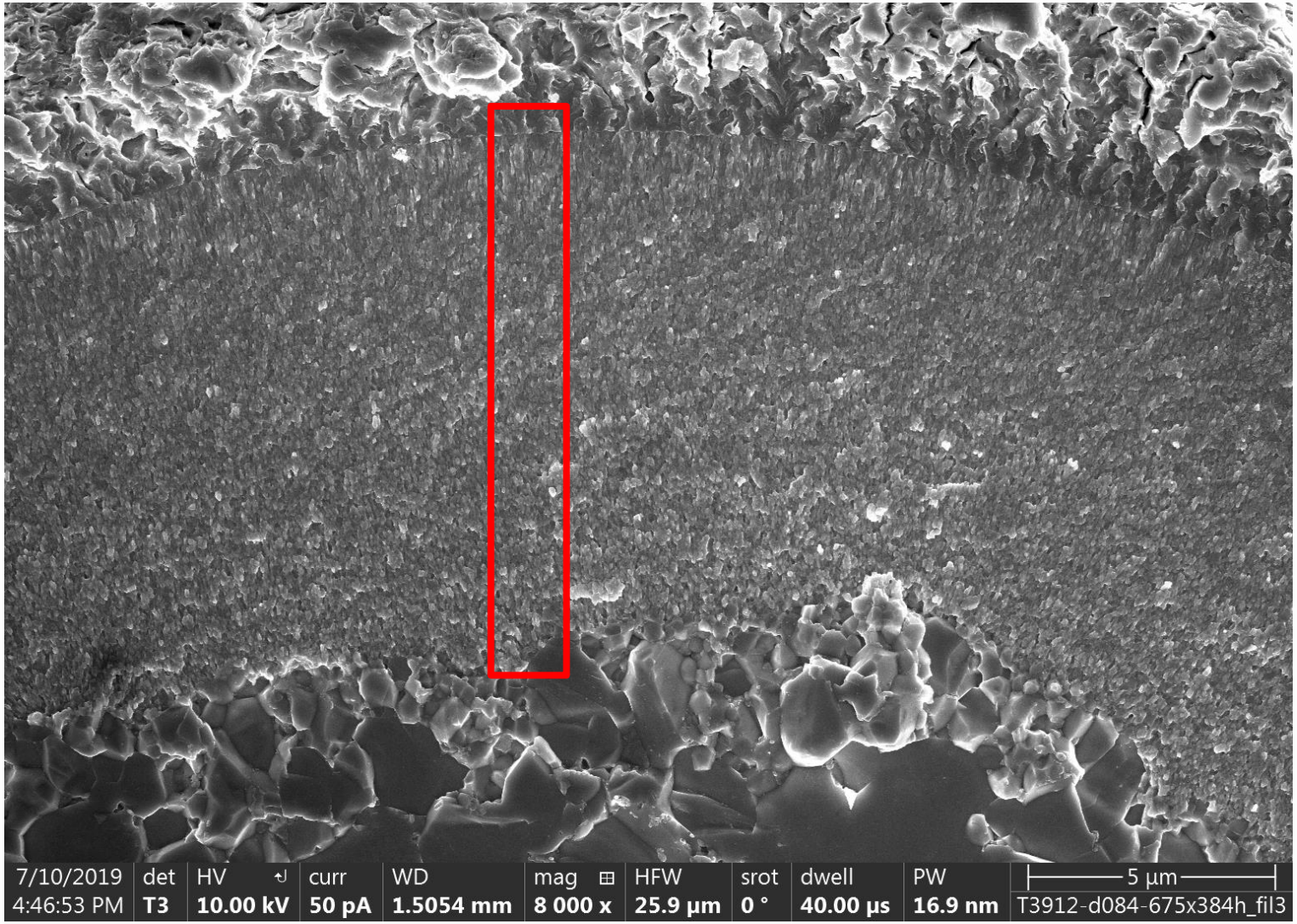
Motivation

- High J_c needed for future accelerators
- Most readily achieved by tuning Nb_3Sn microstructure
- Internal oxidation gives finer grain size
  - ZrO_2 precipitates pin the grain boundaries of Nb_3Sn
- Optimization requires detailed study of microstructure

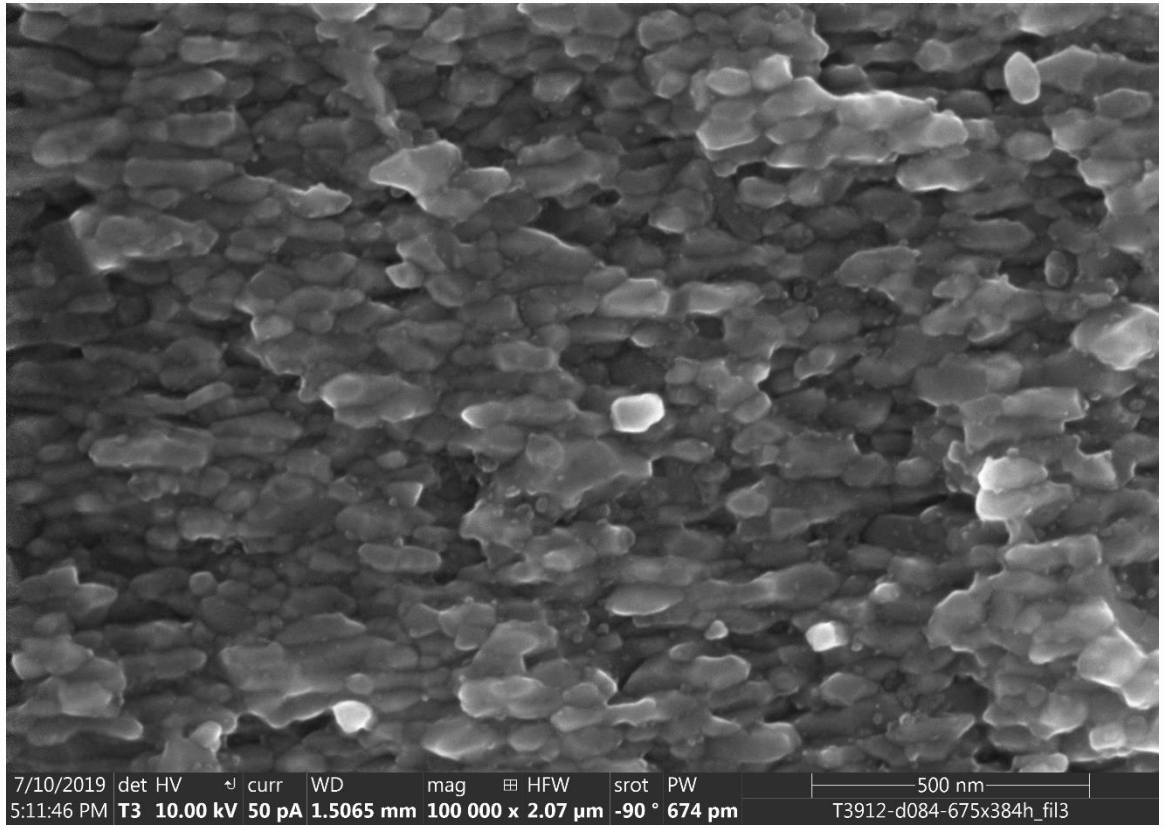
Wire Fabrication

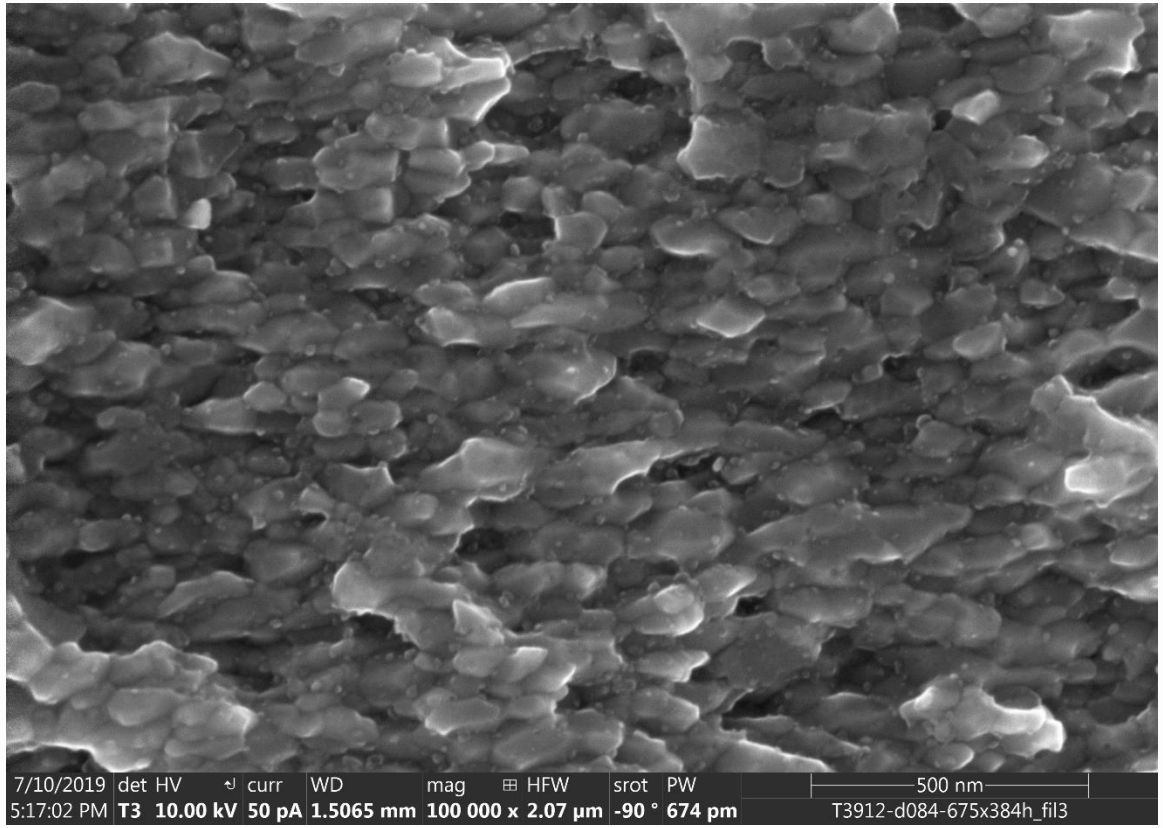
- Wire Name: T3912
- Tube Alloy: Nb-7.5wt%Ta-1wt%Zr
- Cu, Sn, and SnO_2 powders in core
- 48 Nb_3Sn filaments (61 including Cu)
- Cu/Non-Cu ratio: 1.3
- Heat Treatment: 675 °C x 384 h

Fine-Grain Nb_3Sn Layer

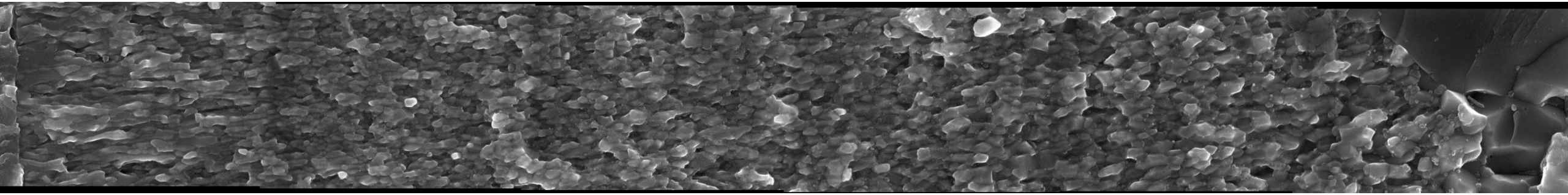


SEM Images Spanning the Layer

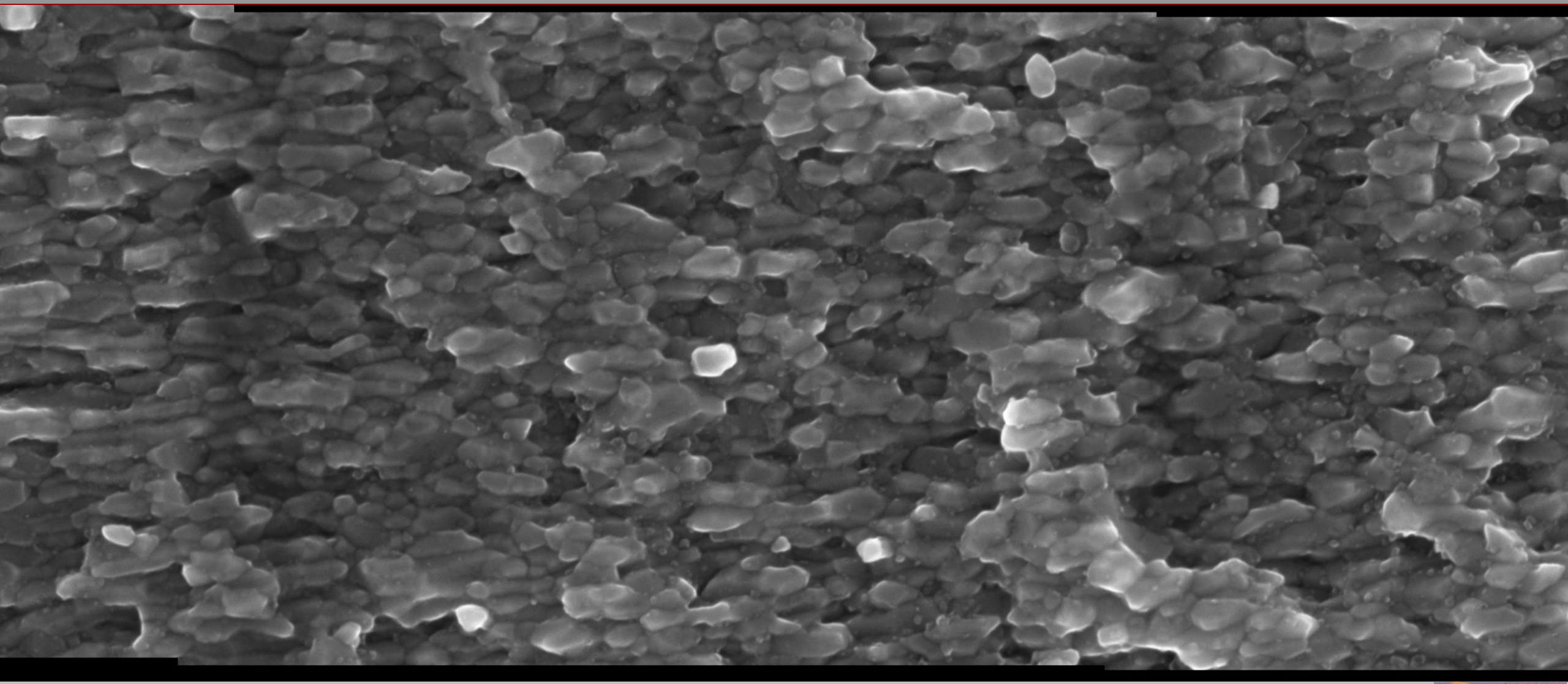




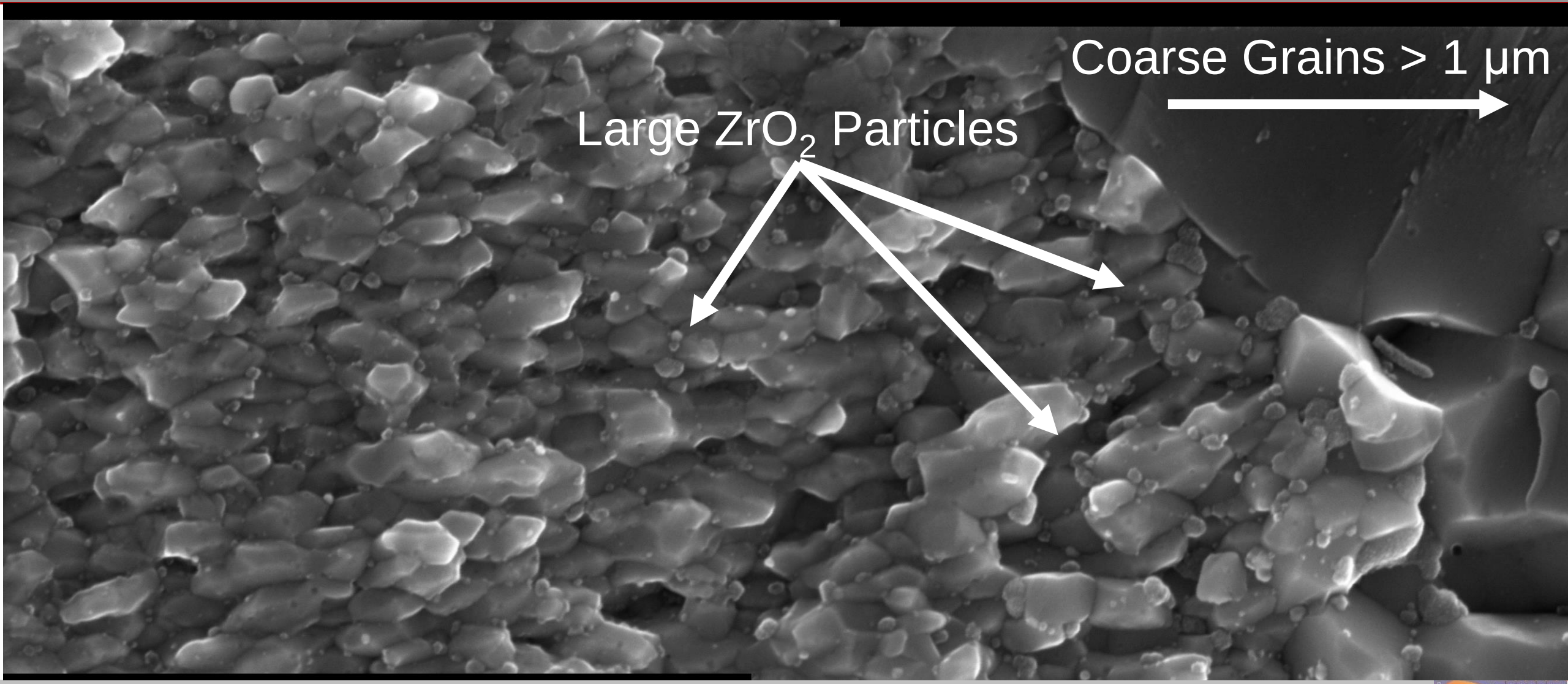
SEM Images Stitched into Panorama



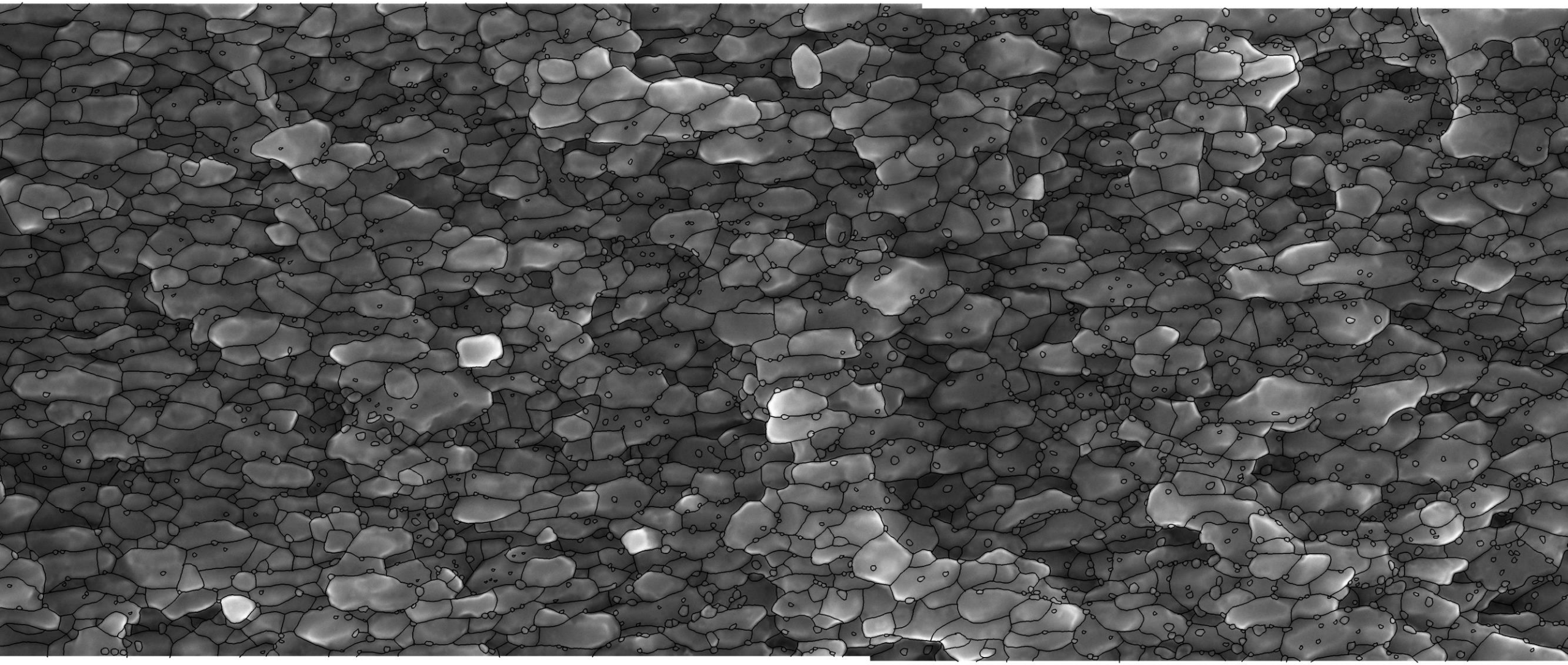
Near the Outside of the Filament



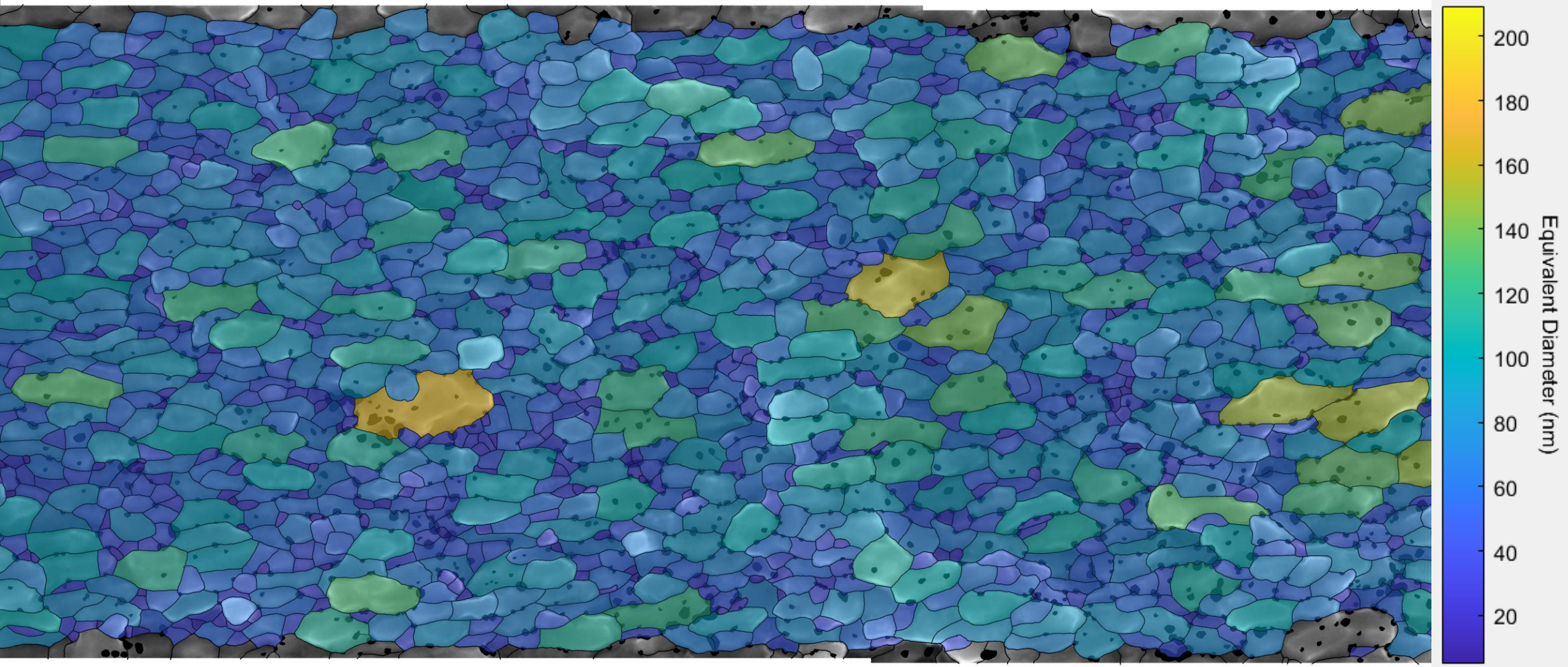
Bordering the Coarse Grain Region



Tracing of Grain Boundaries

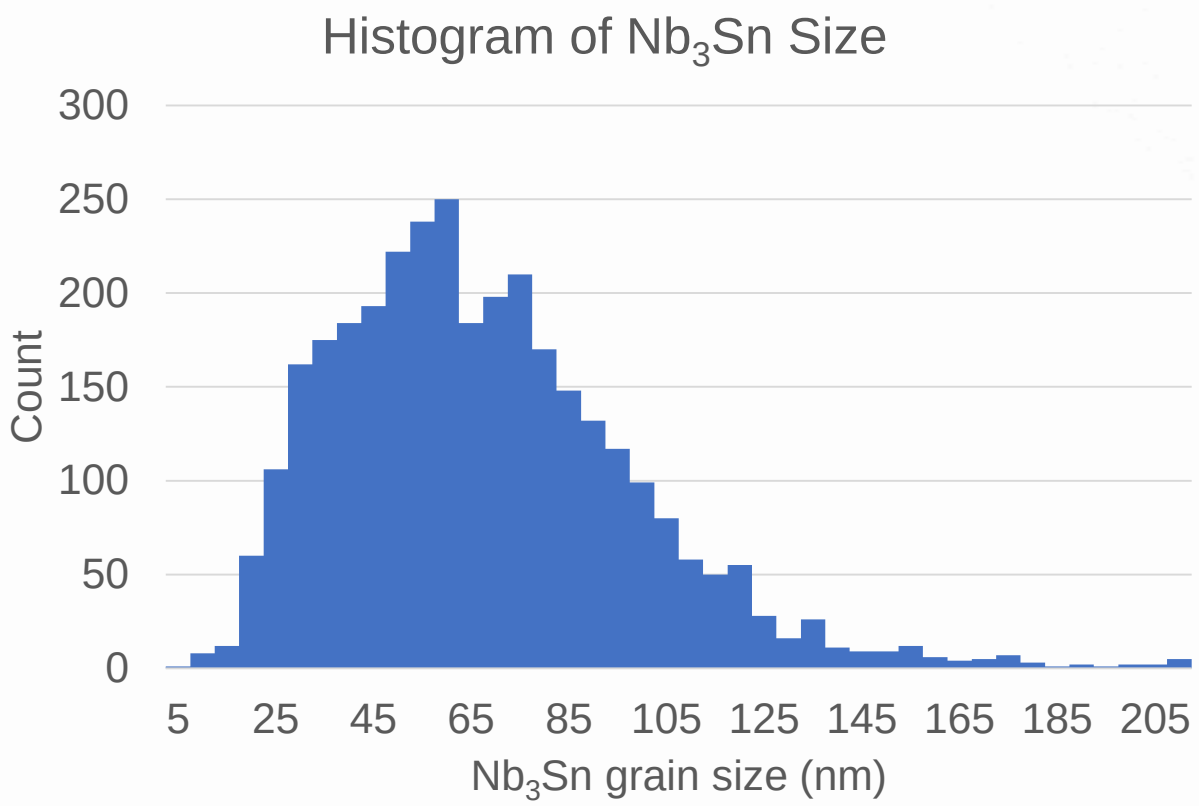


Segmentation



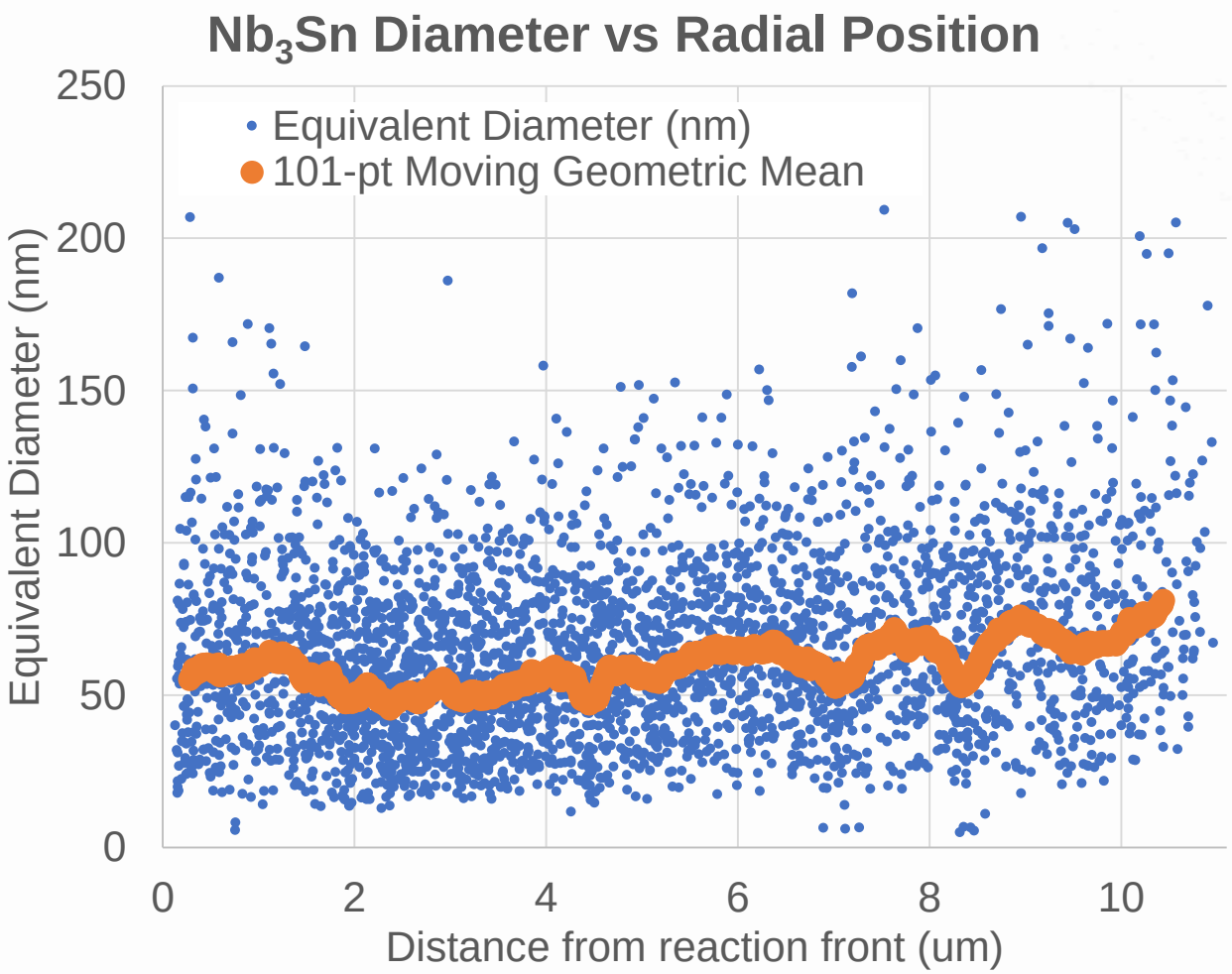
Nb_3Sn Grain Size

- Log-normal distribution
- How to state grain size: Equivalent Diameter
  - **71.7 nm** Mean grain area (physical)
  - **58.0 nm** Geometric mean diameter (statistical)

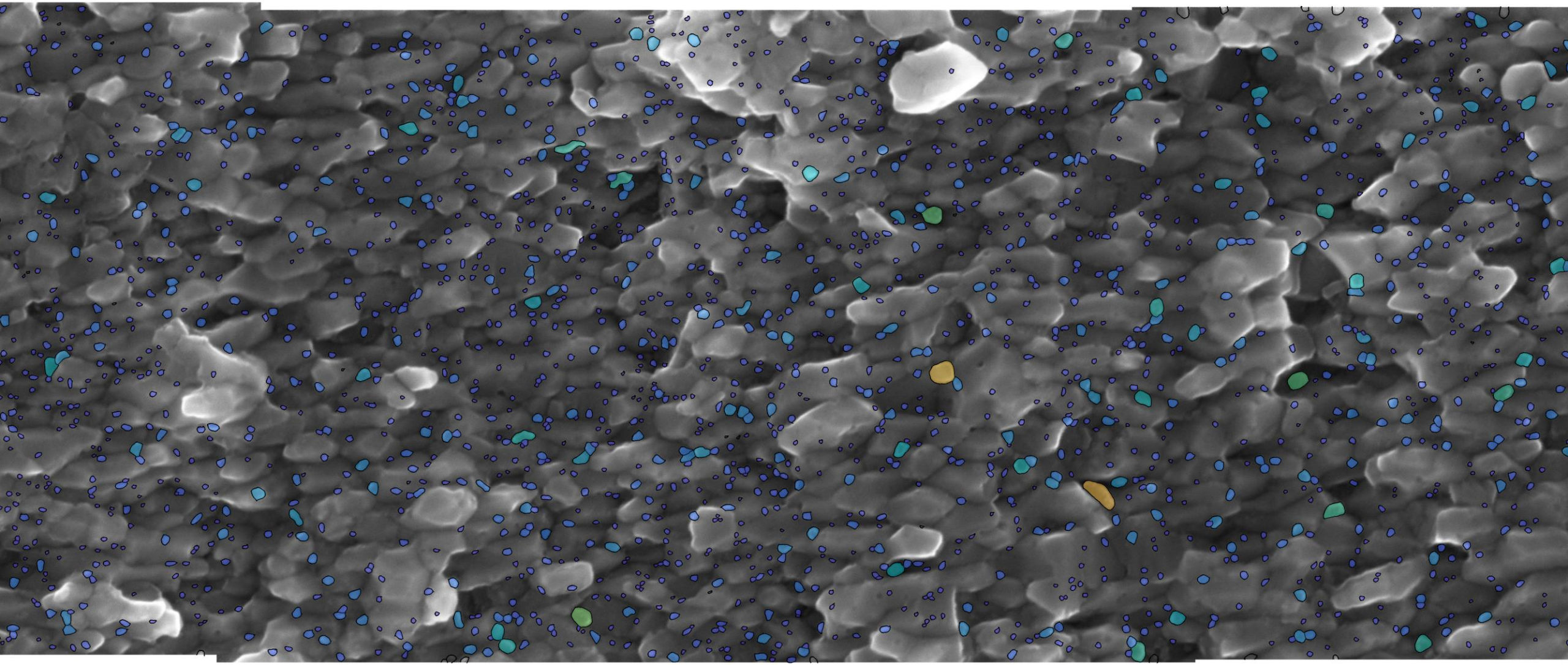


Radial Variation of Grain Size

- Larger grains near the filament core
- Decrease in size towards outside
- Bump in size at edge due to columnar grains

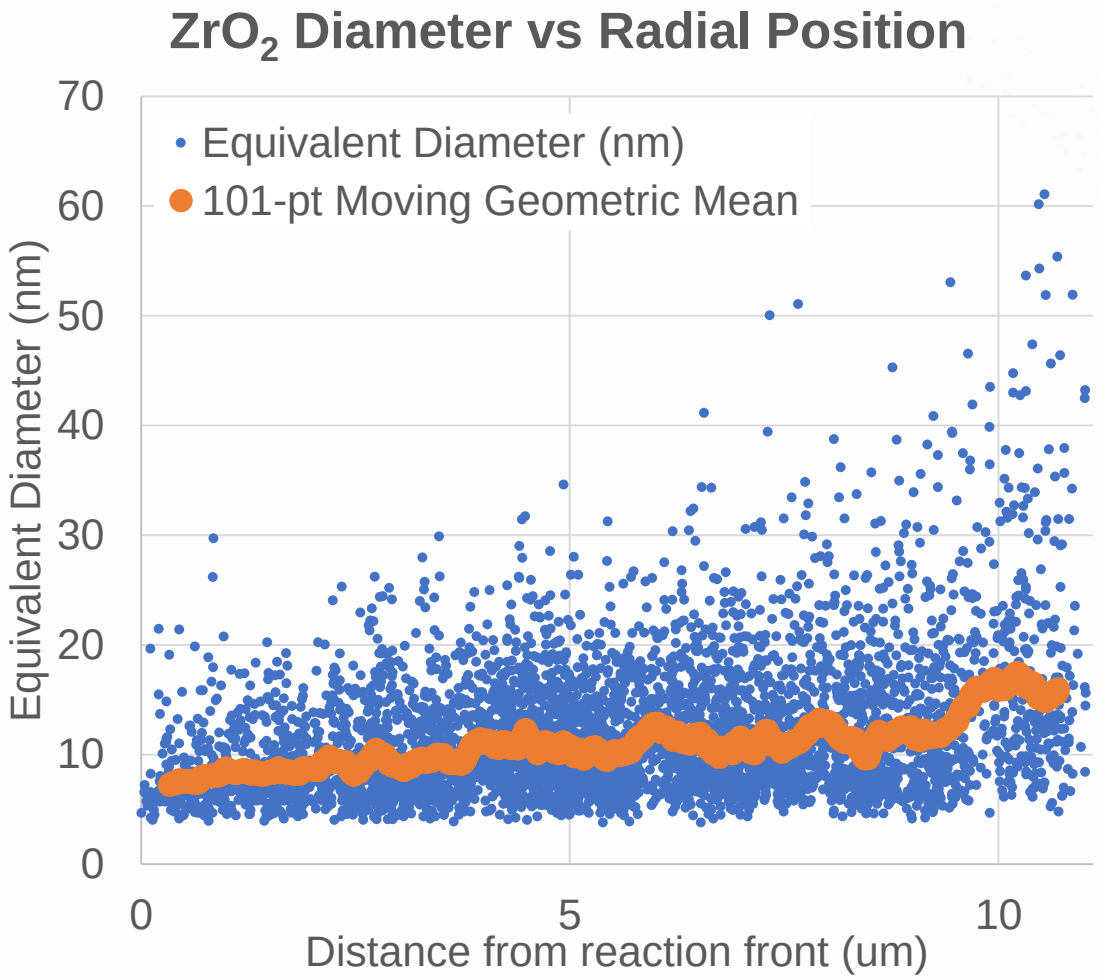


ZrO_2 Precipitates



ZrO_2 Precipitates

- Larger ZrO_2 particles appear near center of filament

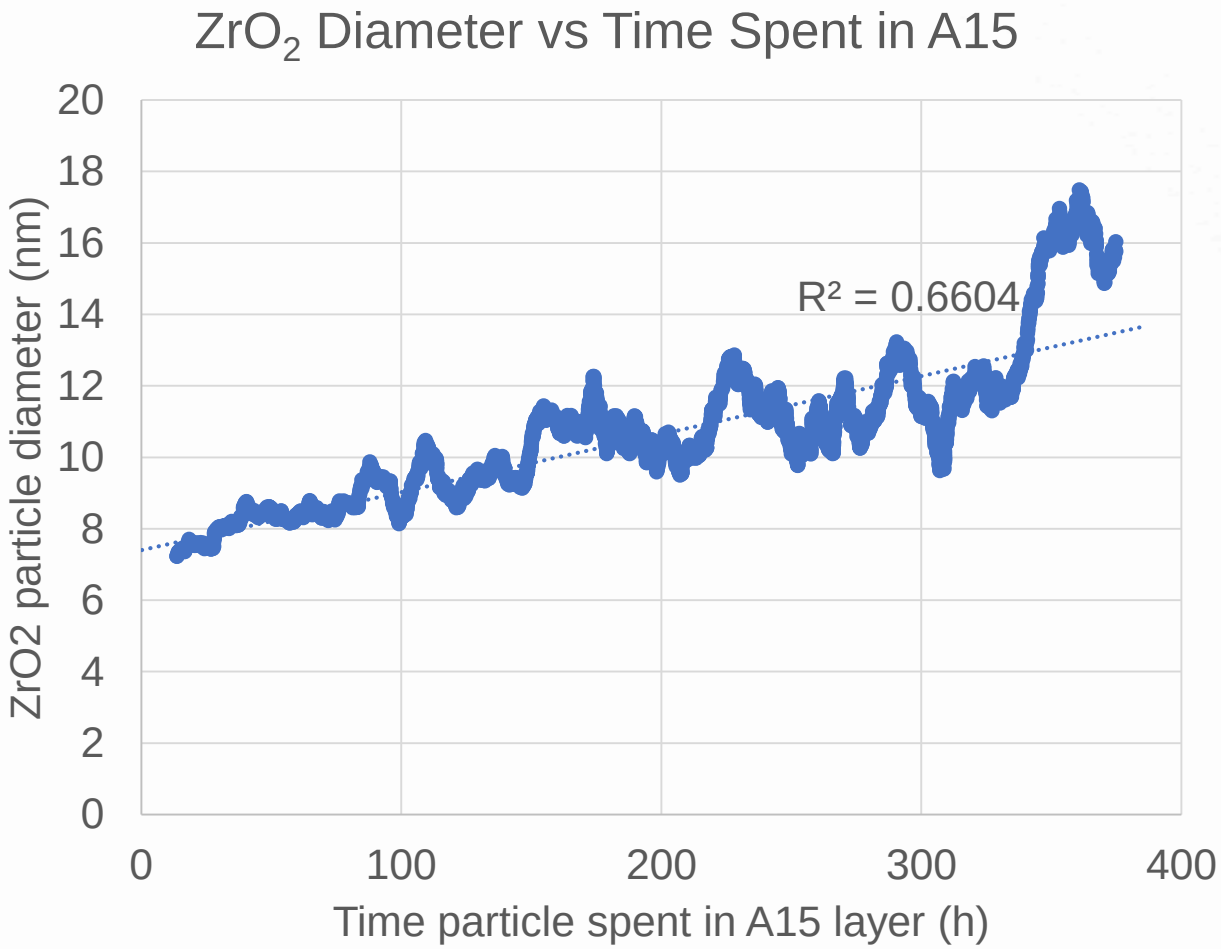


Some Caveats

- Best efforts were made to outline all precipitates
- Hand tracing is accurate to ~ 3 nm (pixel width = 0.674 nm)
- Locations where ZrO_2 was pulled off surface were excluded
- Precipitates smaller than ~ 5 nm are difficult to see but are almost certainly present
  - Future work should include TEM analysis to find ZrO_2 of all scales

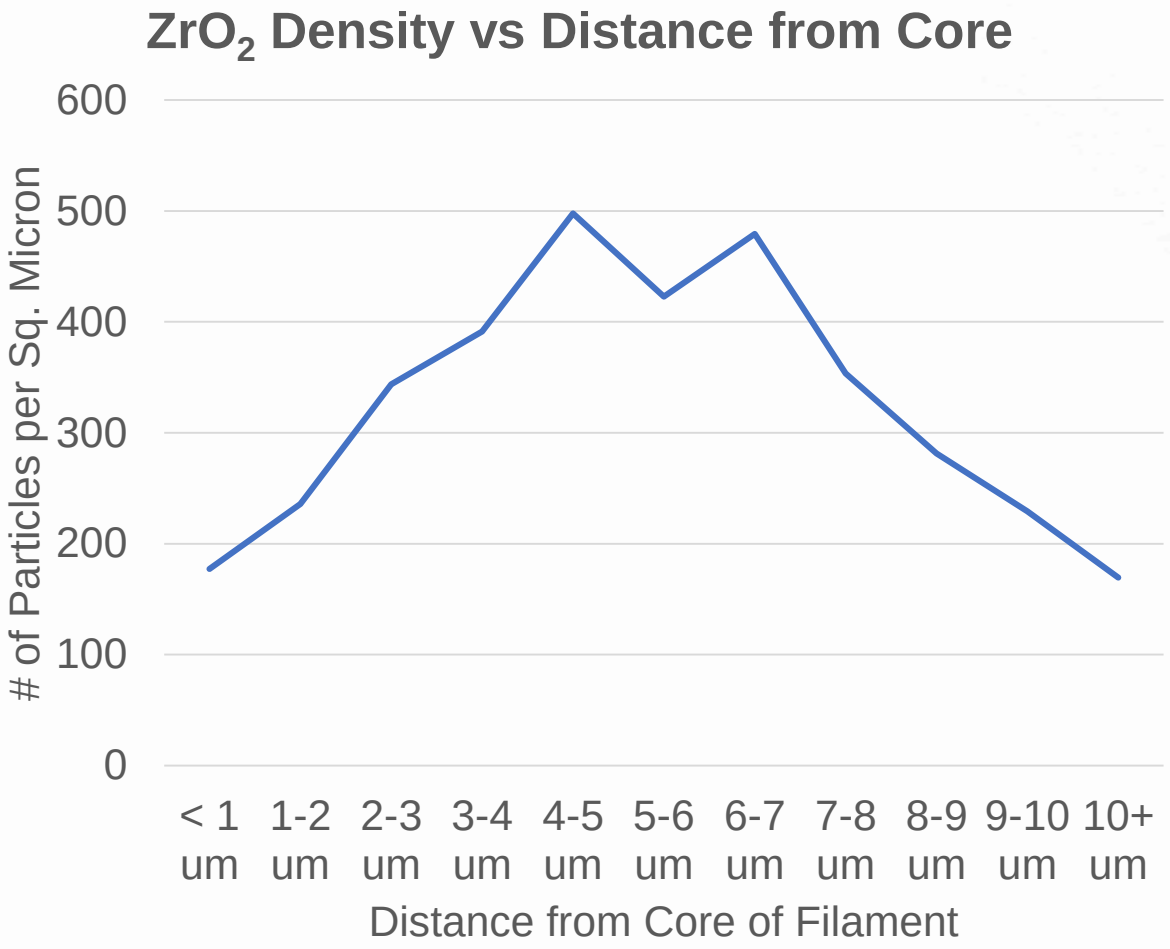
ZrO_2 Size vs Time Spent in A15 Phase

- If we assume cylindrical diffusion of Sn, can correlate radial position to time spent in Nb_3Sn phase
- ZrO_2 is created alongside Nb_3Sn
- So, ZrO_2 appears to coarsen over time



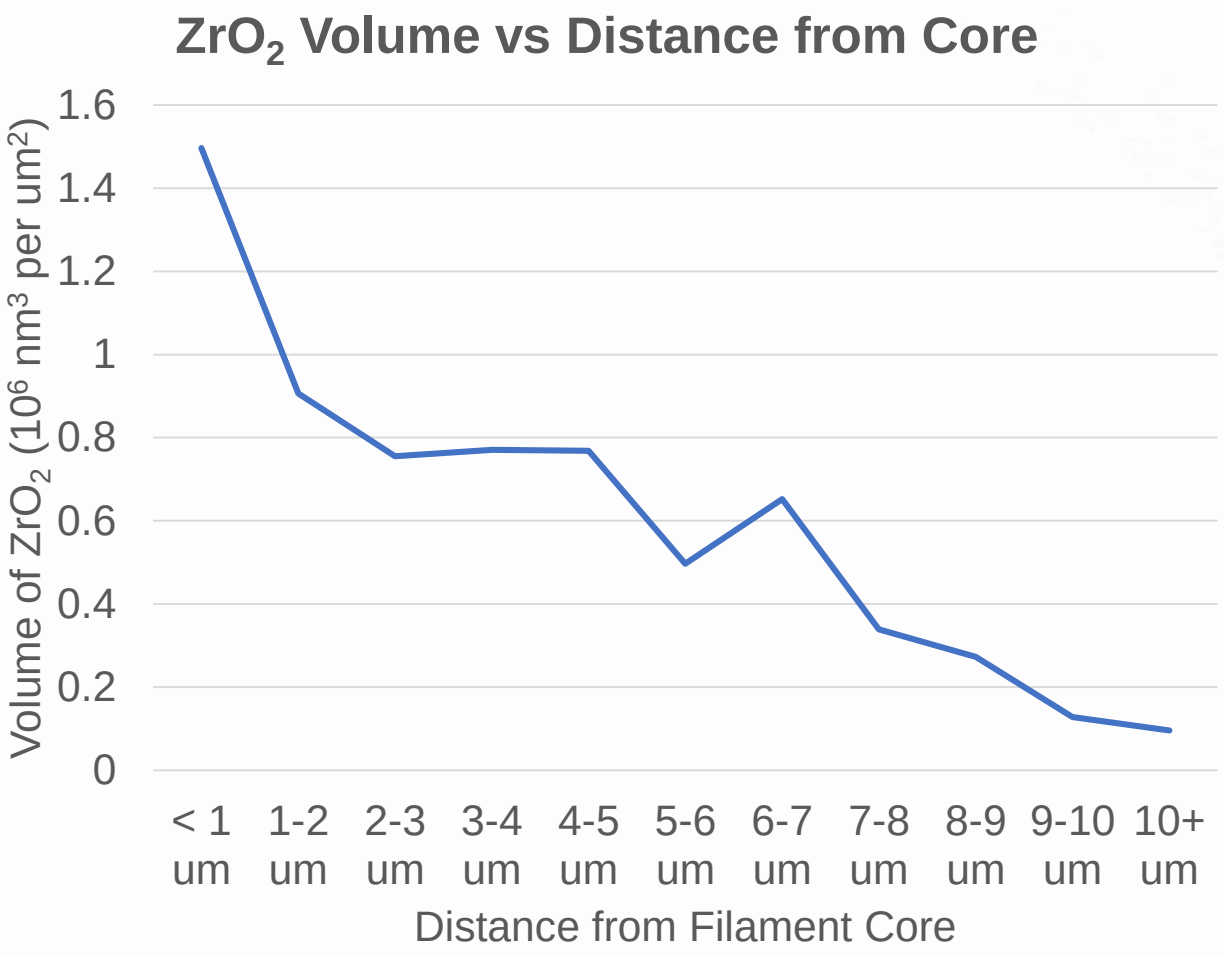
Number Density of ZrO_2

- Can extract number density of ZrO_2 (per square micron)
- Fewer larger particles near core
- Either fewer near outside, or too small to see



Total Volume of ZrO_2

- ZrO_2 volume per square micron appears to decrease from center of filament to edge



Conclusion

- The grain size distribution has been characterized for a recent APC Nb_3Sn wire
- The area-weighted mean diameter is refined to 71.7 nm at a 675 °C heat treatment
- ZrO_2 tends to grow in size and reduce in frequency with heat treatment time
  - This correlates to an increase in Nb_3Sn grain size near the filament core

References

- All the wires were manufactured by Hyper Tech, which are funded by the US Department of Energy, Office of High Energy Physics, SBIR Phase I & Phase II Grant No. DE-SC0017755, DE-SC0013849. This work was also partially supported by the Fermilab LDRD program.
- Electron microscopy was performed at the Center for Electron Microscopy and Analysis (CEMAS) at The Ohio State University.
- Image analysis was performed using FIJI/ImageJ as well as MIPAR, a recipe-based image processing software.

Thank you!